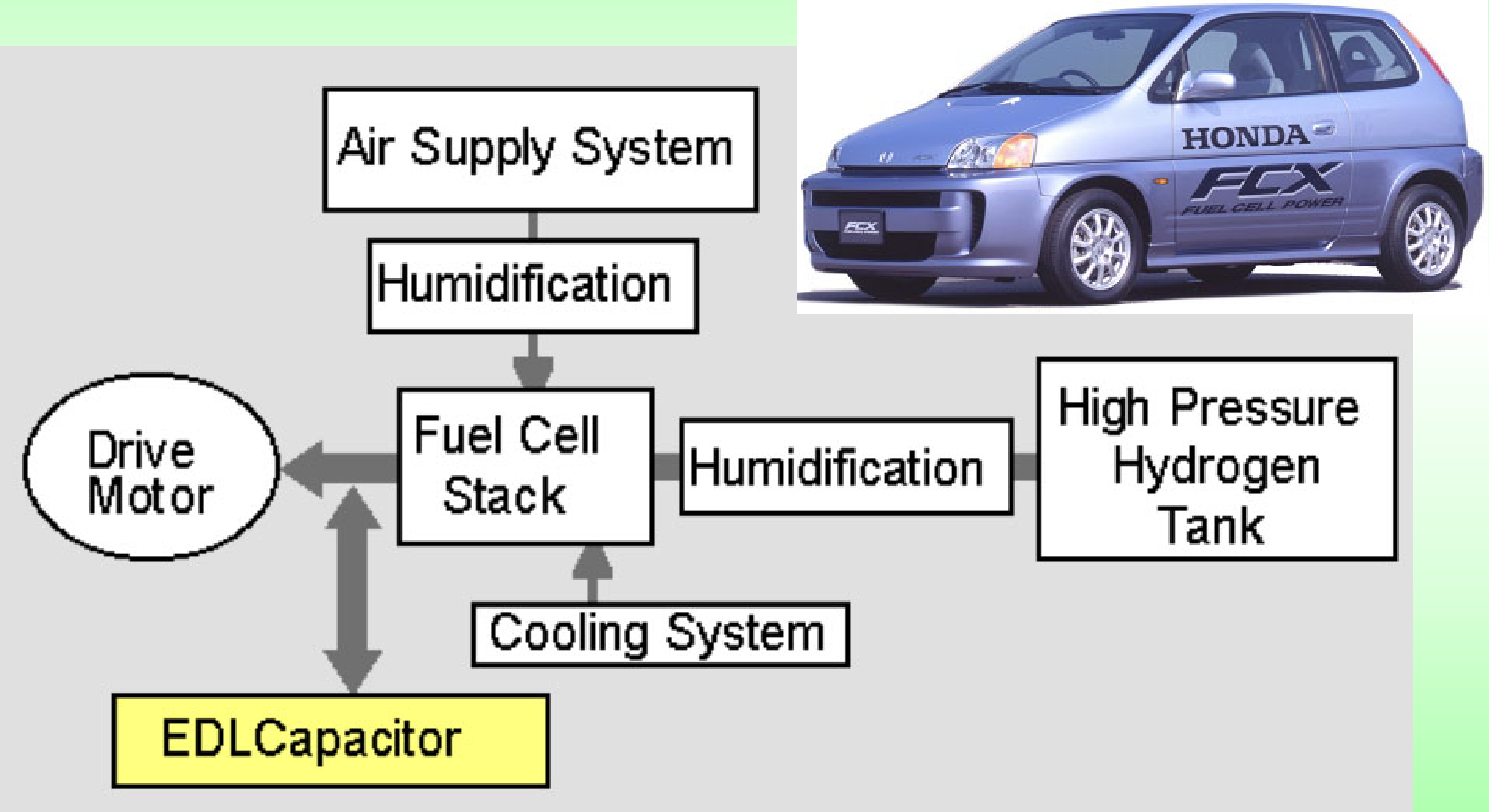
Capacitor Storage Systems

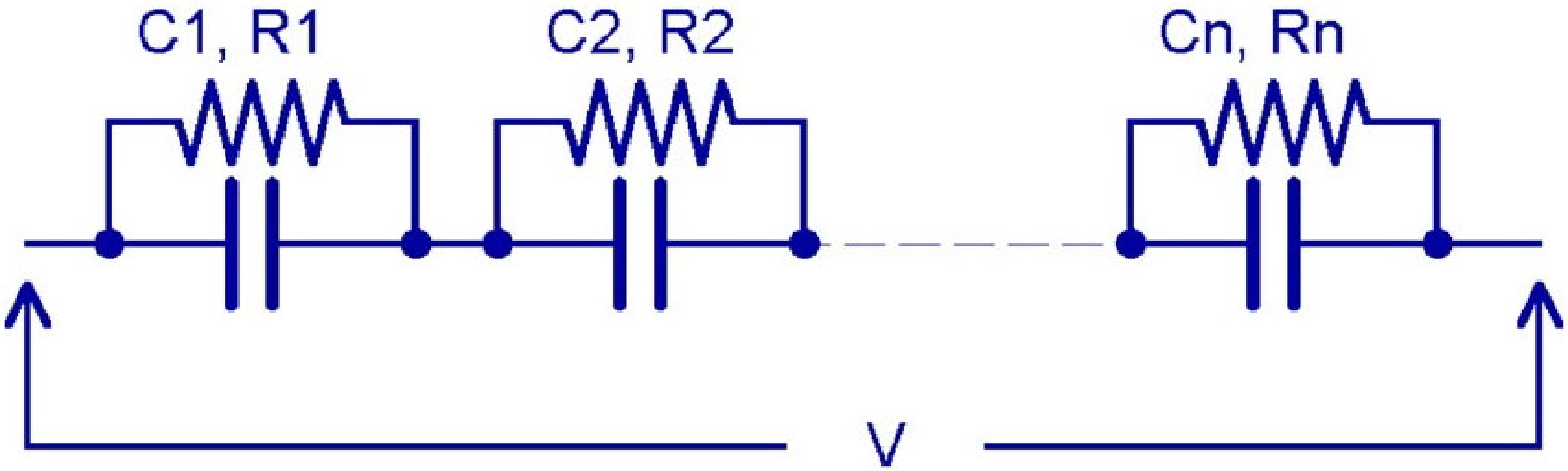
- **Behavior of serially connected capacitors and their control methods**
- **Characteristics and safety of PC and AN based electrolytes**
- **Design of capacitors for optimum internal resistance and energy density**

Parallel Capacitor Hybrid Truck

Fuel Cell + Capacitor Hybrid

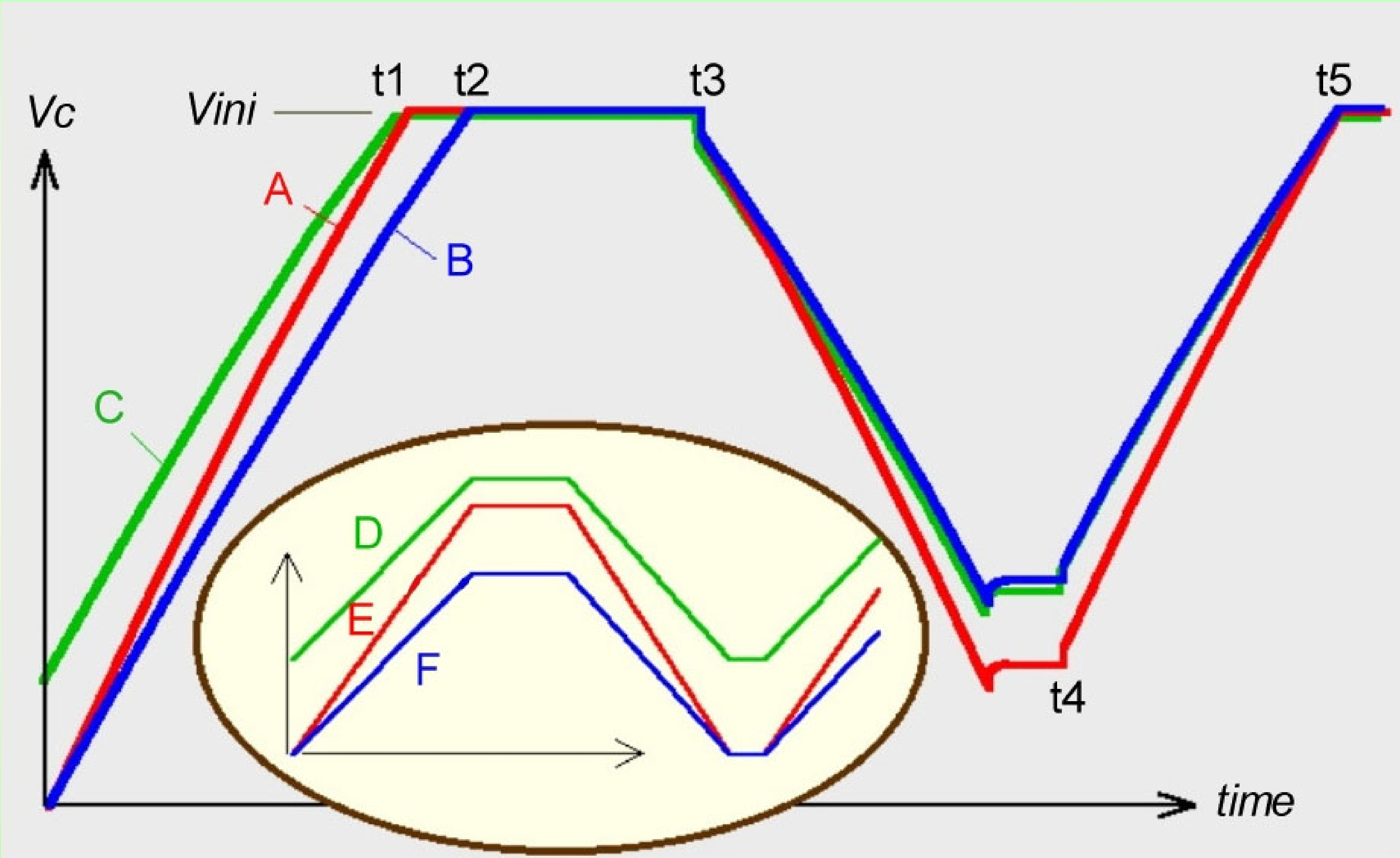


Capacitor Serial Connection



$$V_X = \left(\frac{k \cdot R_X}{R_1 + \ldots + R_n} + \frac{(1-k) \cdot {}^1\!/\!_{C_X}}{{}^1\!/\!_{C_1} + \ldots + {}^1\!/\!_{C_n}} \right) \cdot V \quad \ldots\ldots(1)$$

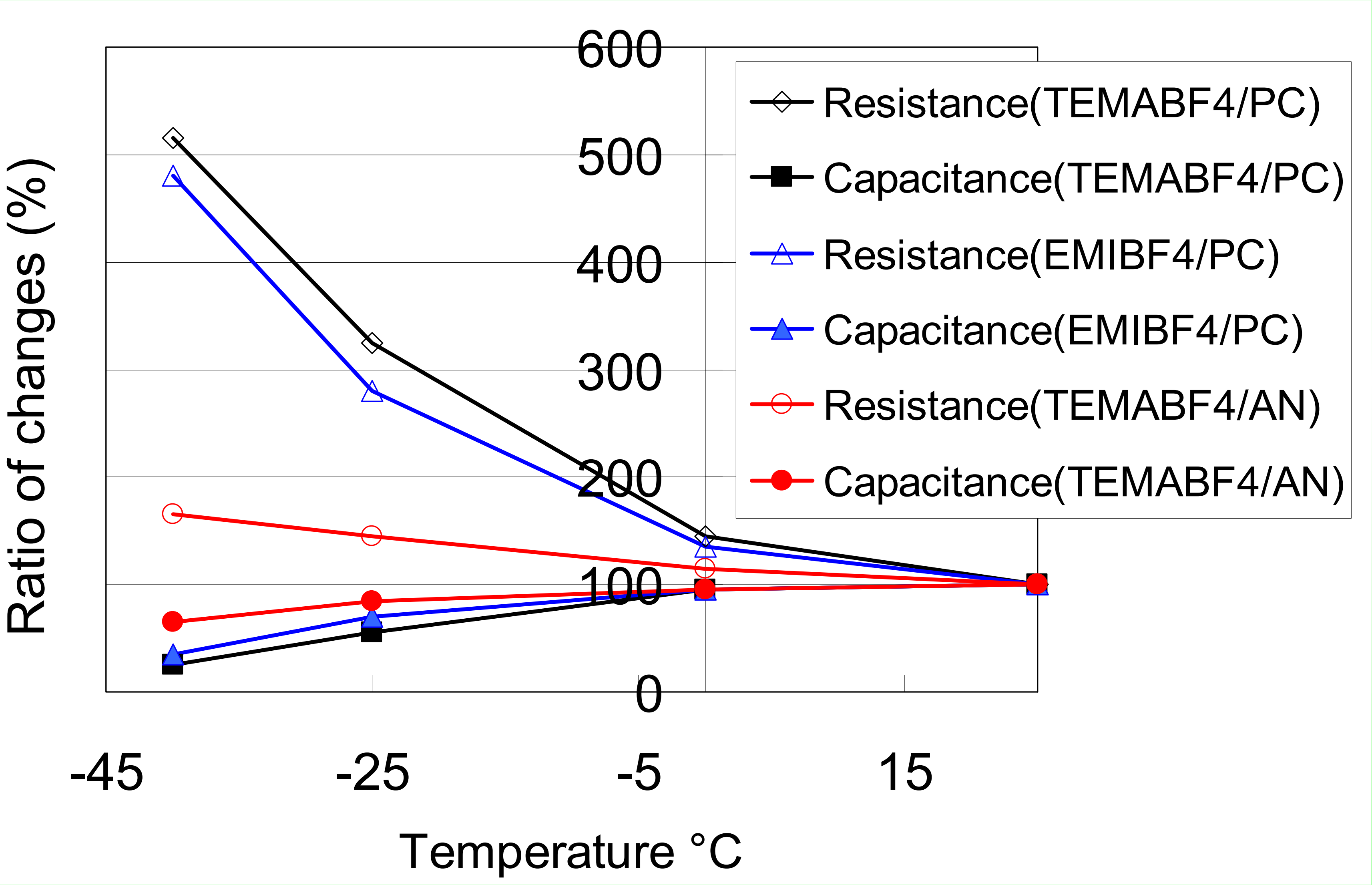
Capacitor Initialization



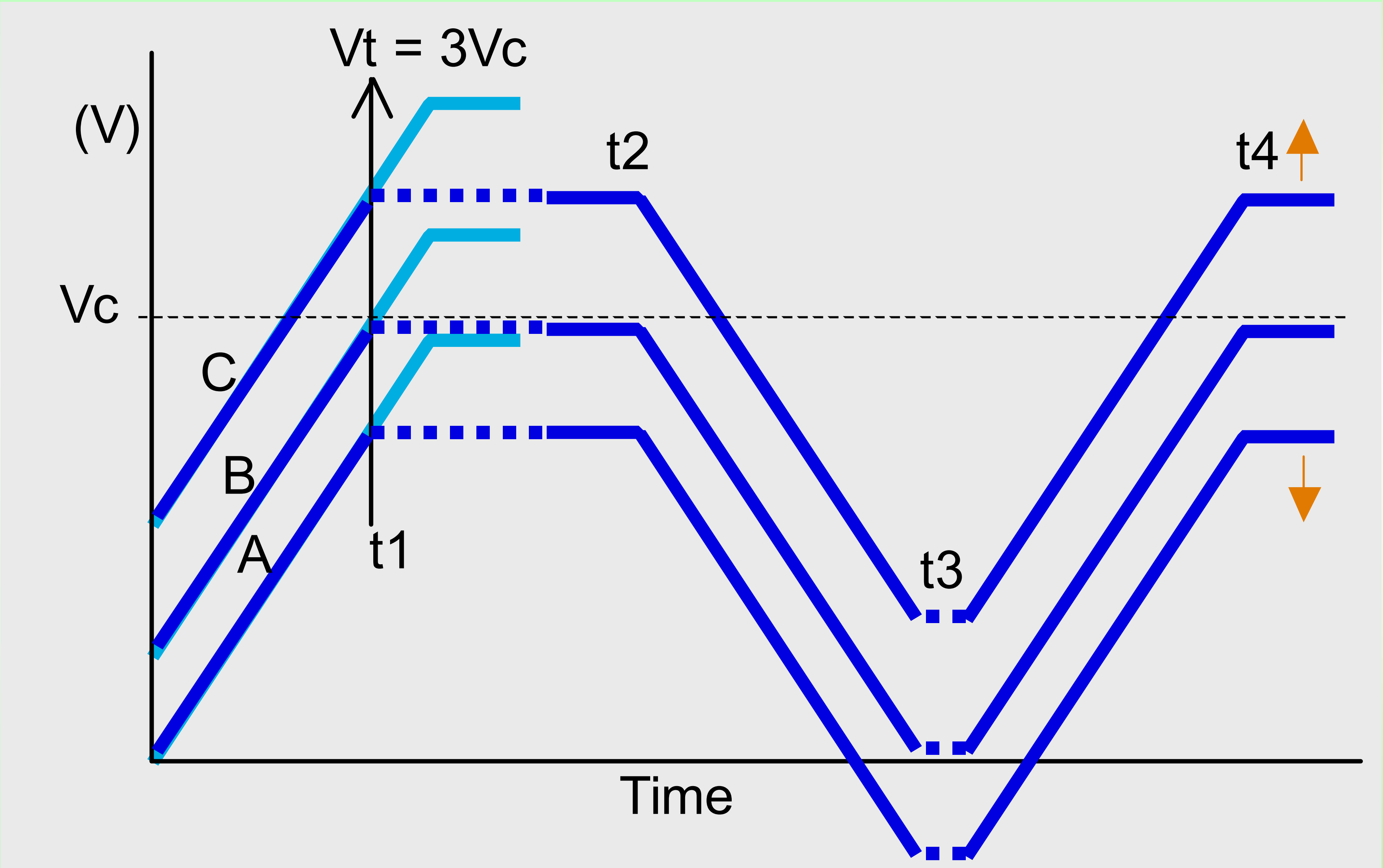
Electrolytes: PC versus AN

PC:	***AN:***
Non-toxic	Toxic
Low-flammable	Highly flammable
→ Light cell case	→ Heavy cell case
Low capacitance	Higher capacitance
High resistance	Lower resistance
Lower max. voltage	Higher max. voltage
→ Low energy density	→ High energy density
High ESR at low temp.	Low ESR at low temp.

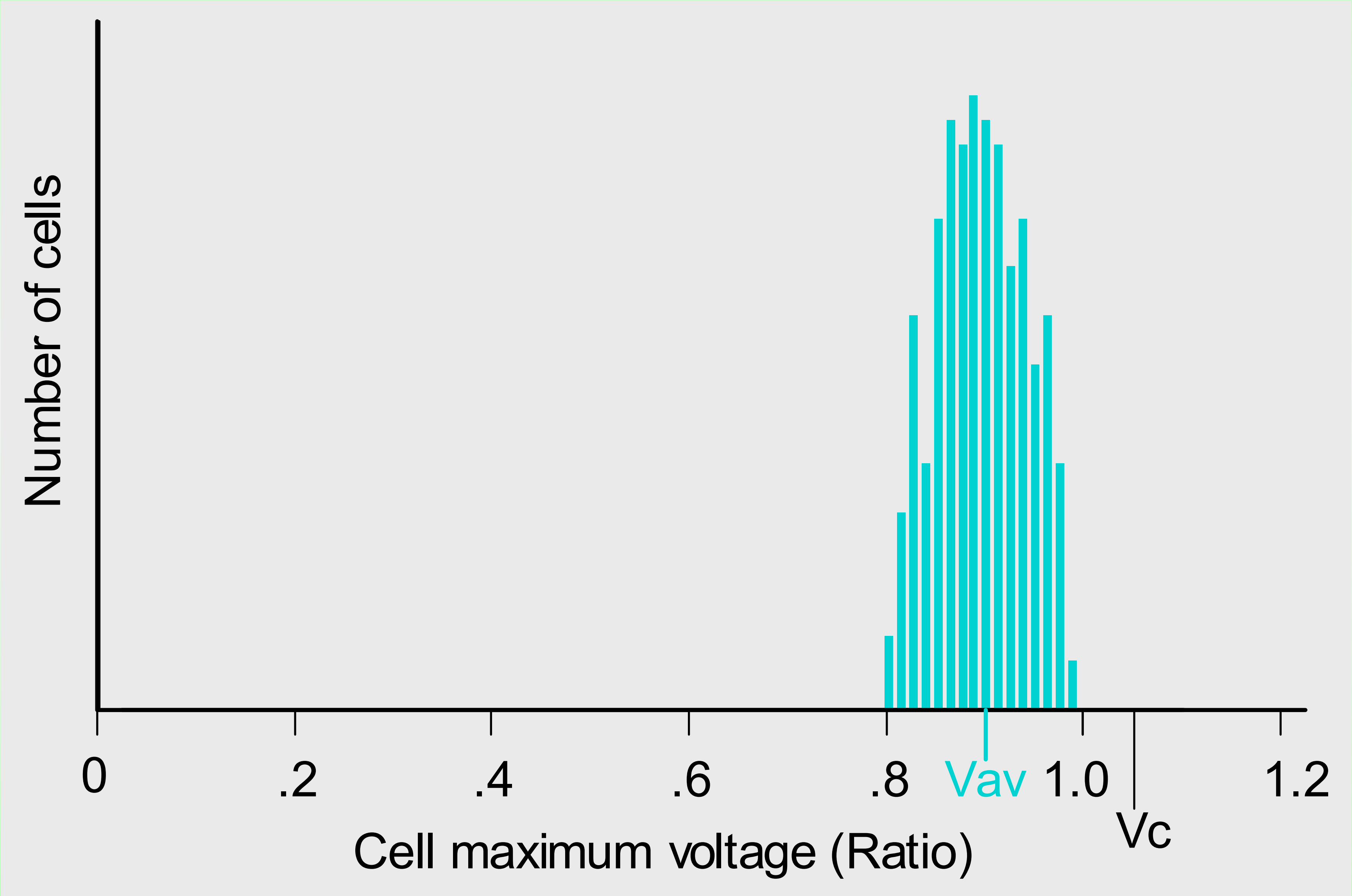
Temperature Dependence



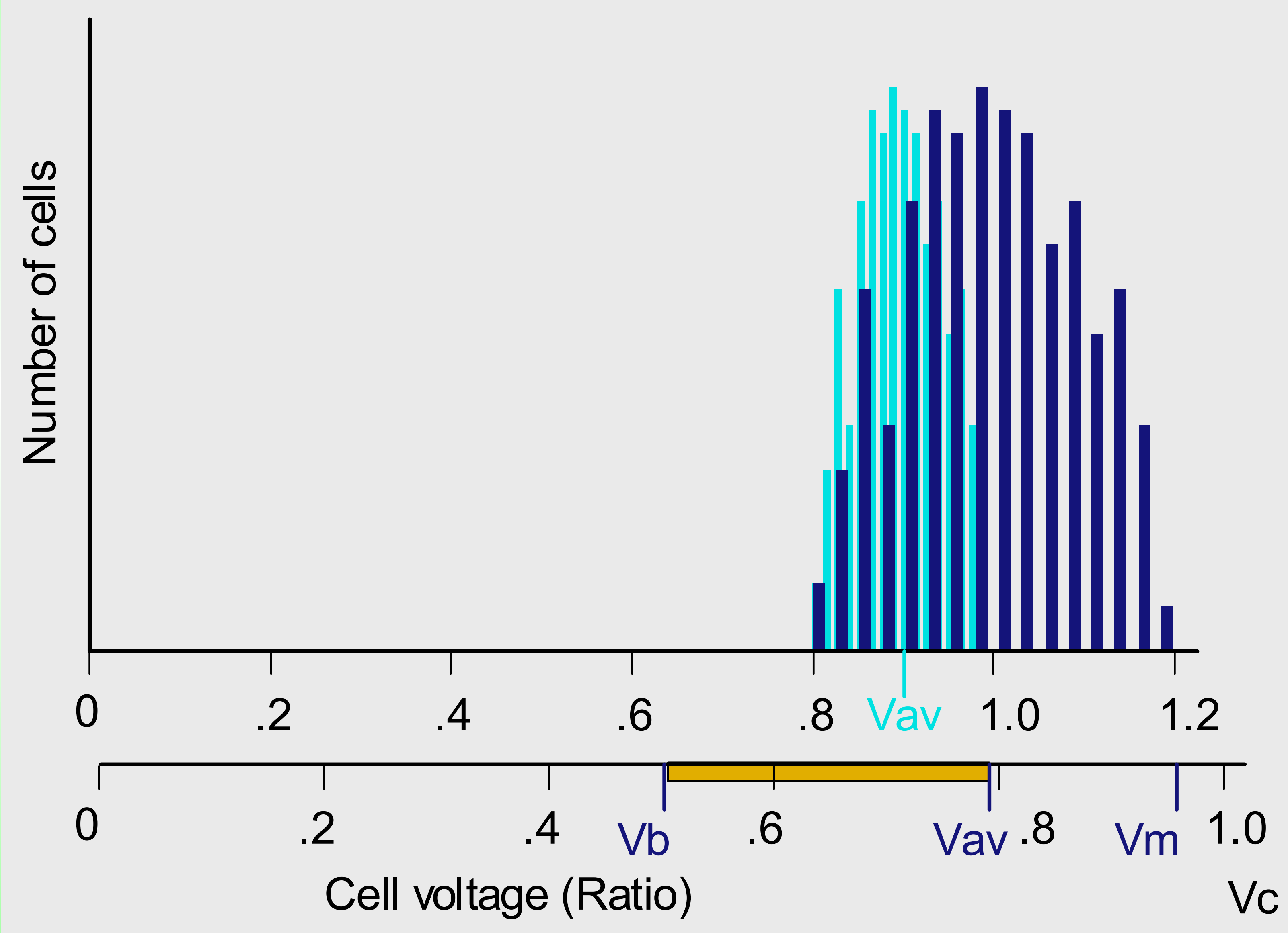
Charging Serial Capacitors



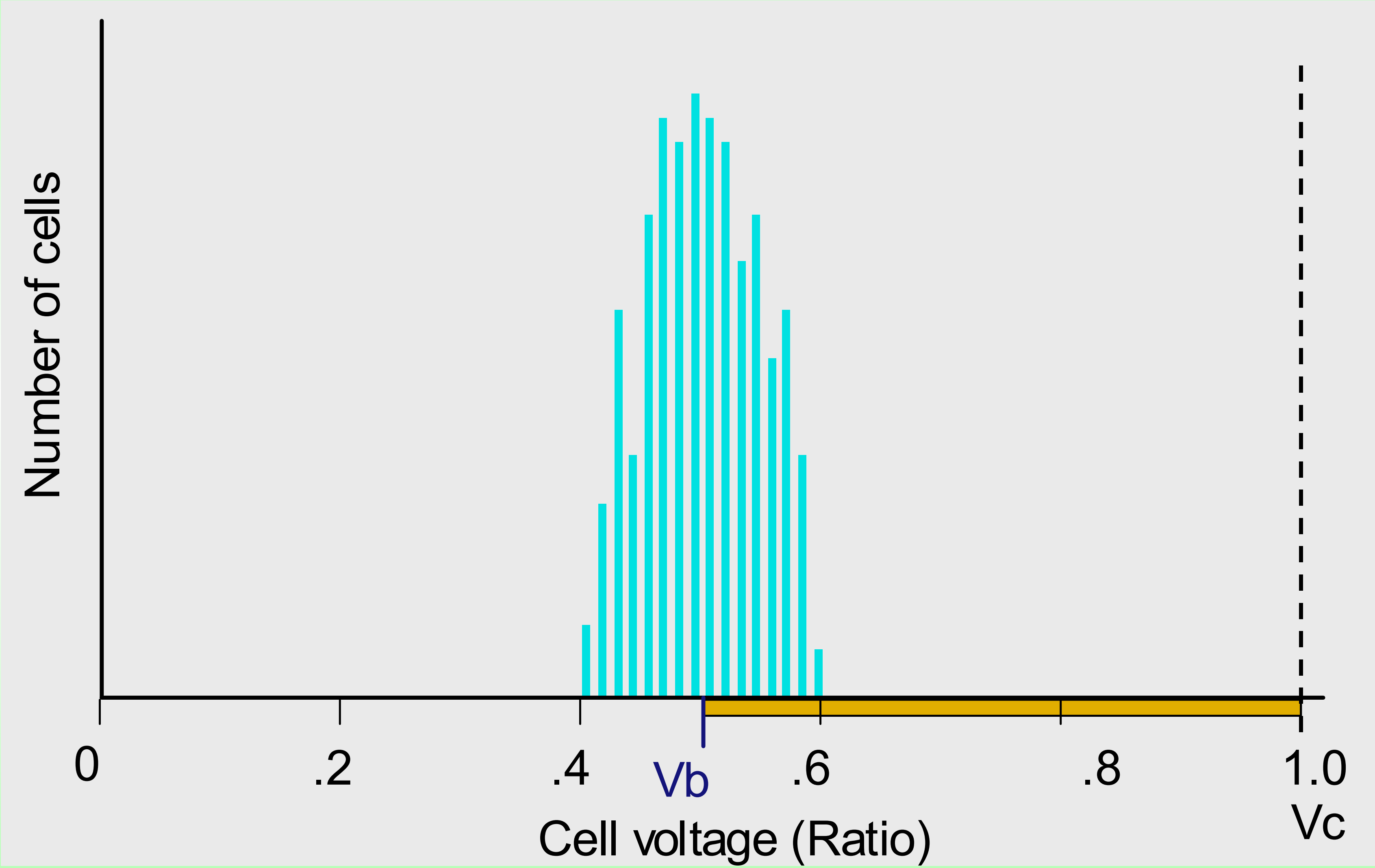
Voltage Distribution of Cells



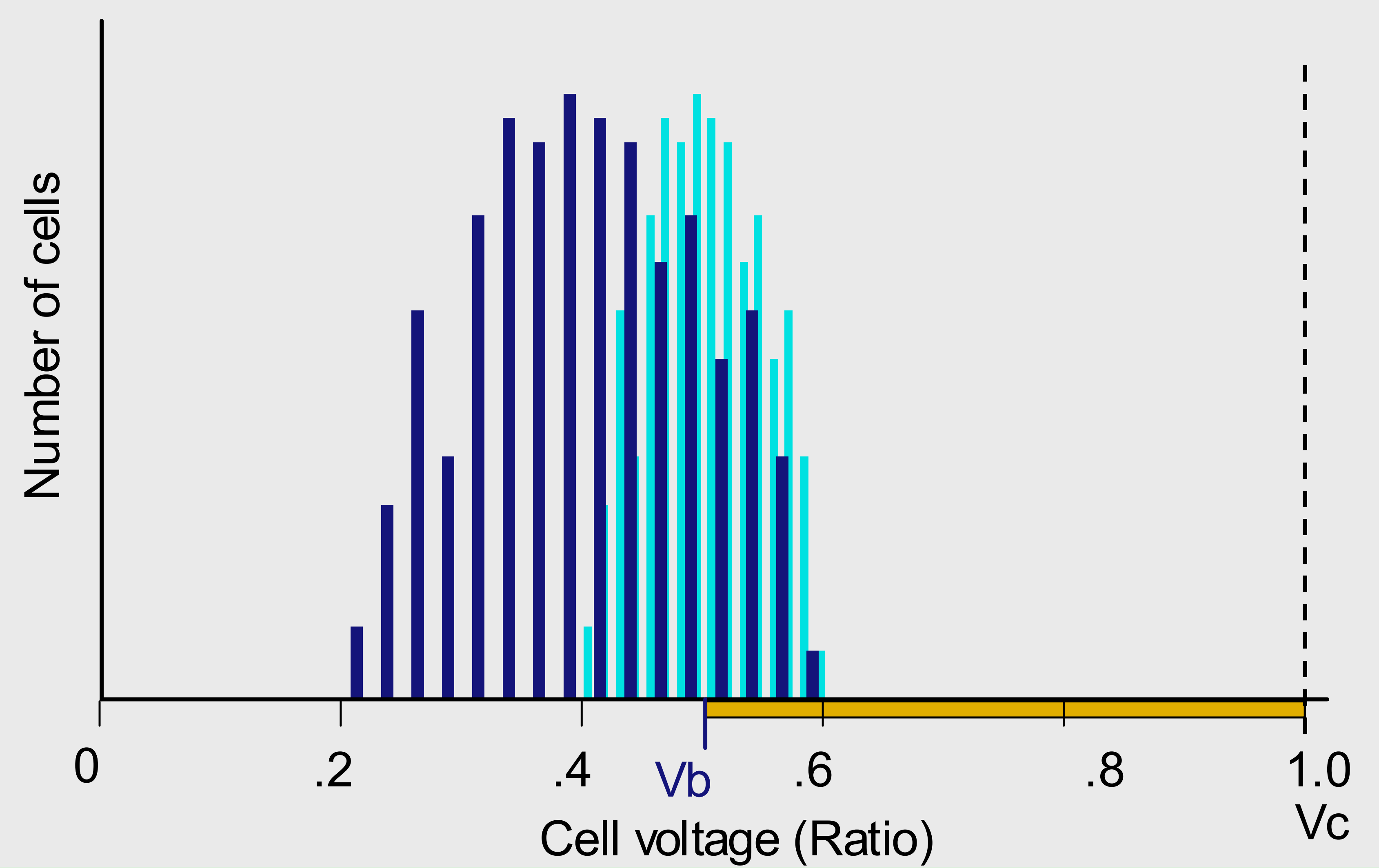
After Aging: 20% Max. Loss



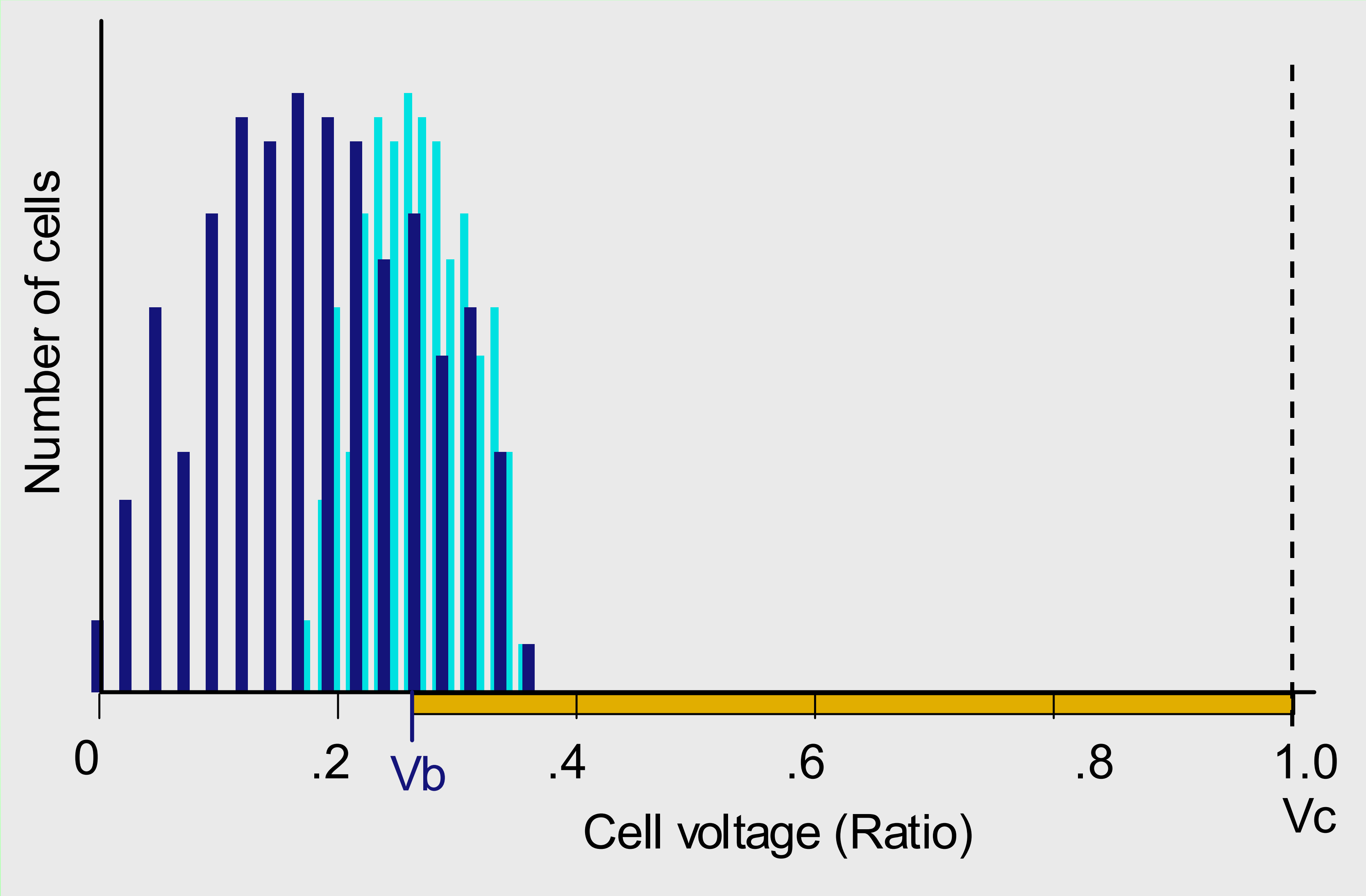
All ECaSS Cells Start at Vc



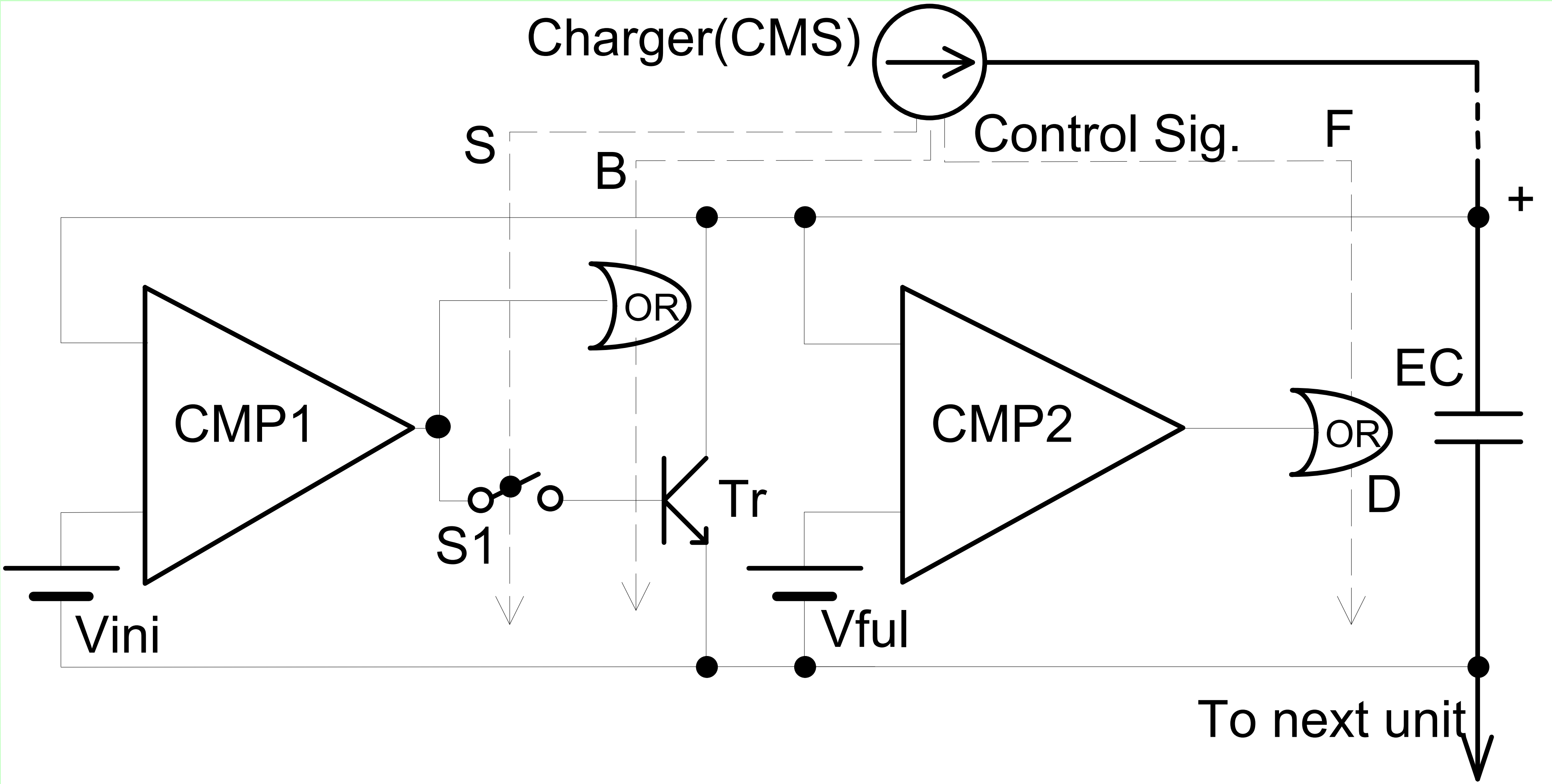
After 20% Aging with ECaSS



94% Discharge at 20% Aging

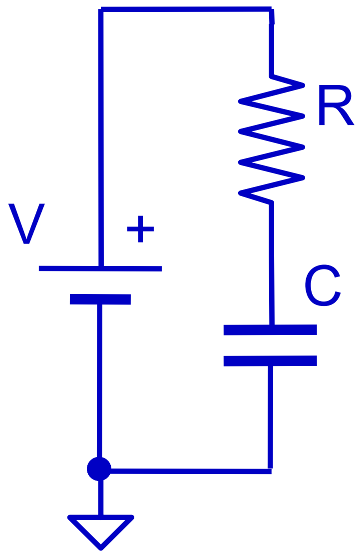


Circuits of a Parallel Monitor

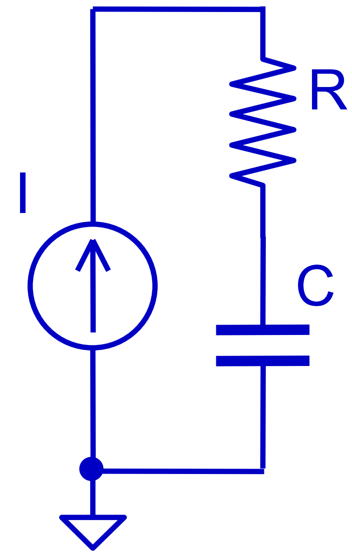


Efficiency Calculation

Voltage mode



Current mode



$$i = \frac{V}{R}\exp\left(-\frac{t}{CR}\right) \quad \ldots\ldots (11)$$

$$\int_0^\infty i^2 R\,dt = \frac{1}{2}CV^2 \quad \ldots\ldots (12)$$

Pc= U / (U + L) = 1/ (1+ 2RC/ t)...(1)

Pd= (U - L) / U = 1- 2RC / t ......(2)

Is Lower Resistance Better?

$$t=U/k \quad \ldots\ldots\ldots\ldots\ldots(4)$$

$$Pd=1-2k(RC/U)\ldots(5)$$

U:capacitor energy density

k:arbitrary constant

The Unit Called “Ohm-Farad”

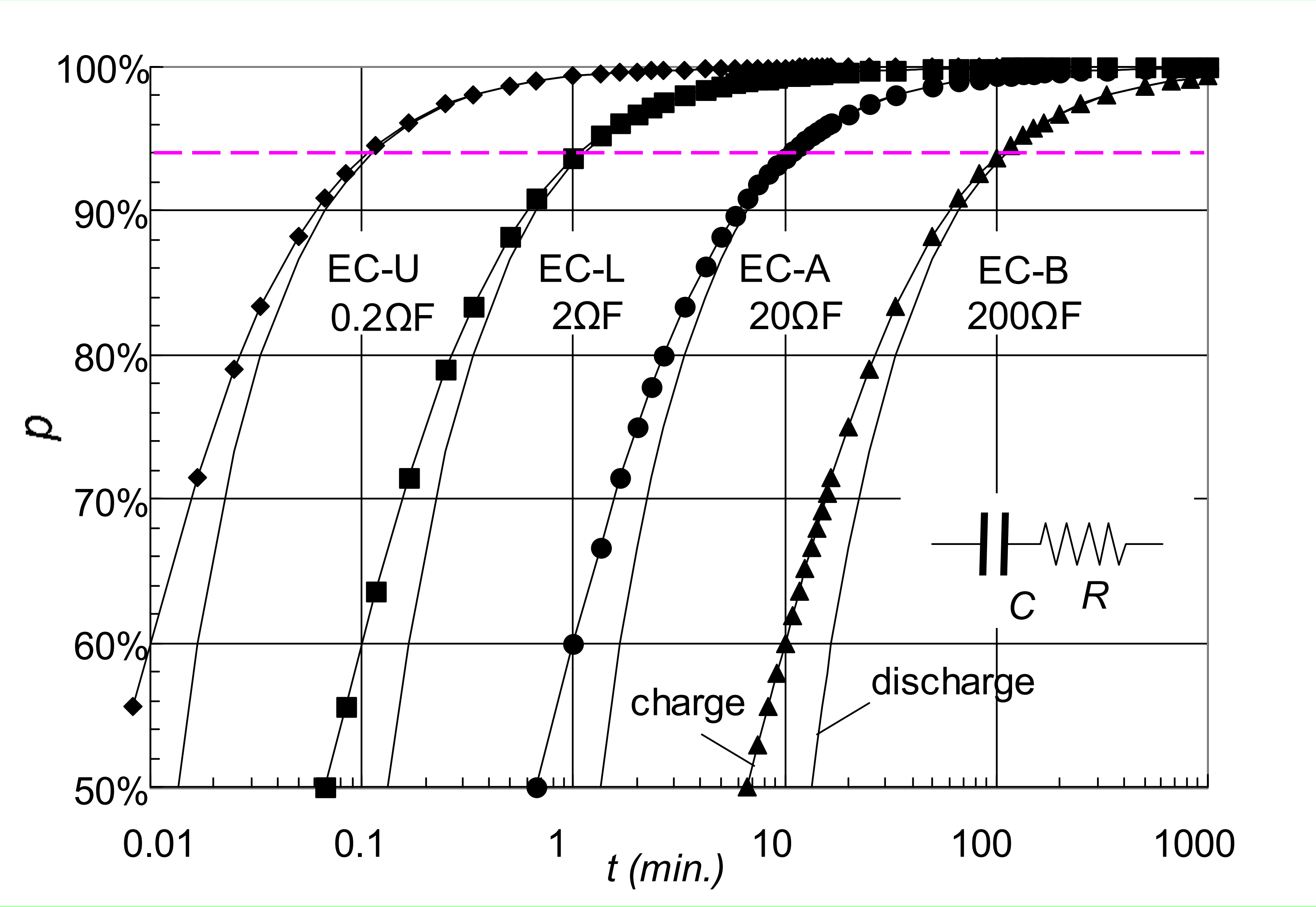
To normalize ESR per capacitance

- Conductivity/Capacity = (Siemens)/(Farad)
- (Siemens) = 1/(Ω)
- (Siemens)/(Farad) = 1/(ΩF)
- Resistivity/Capacity = 1/1/(ΩF) = (ΩF)

Pc = 1/(1+2**RC/t**) ... (2)

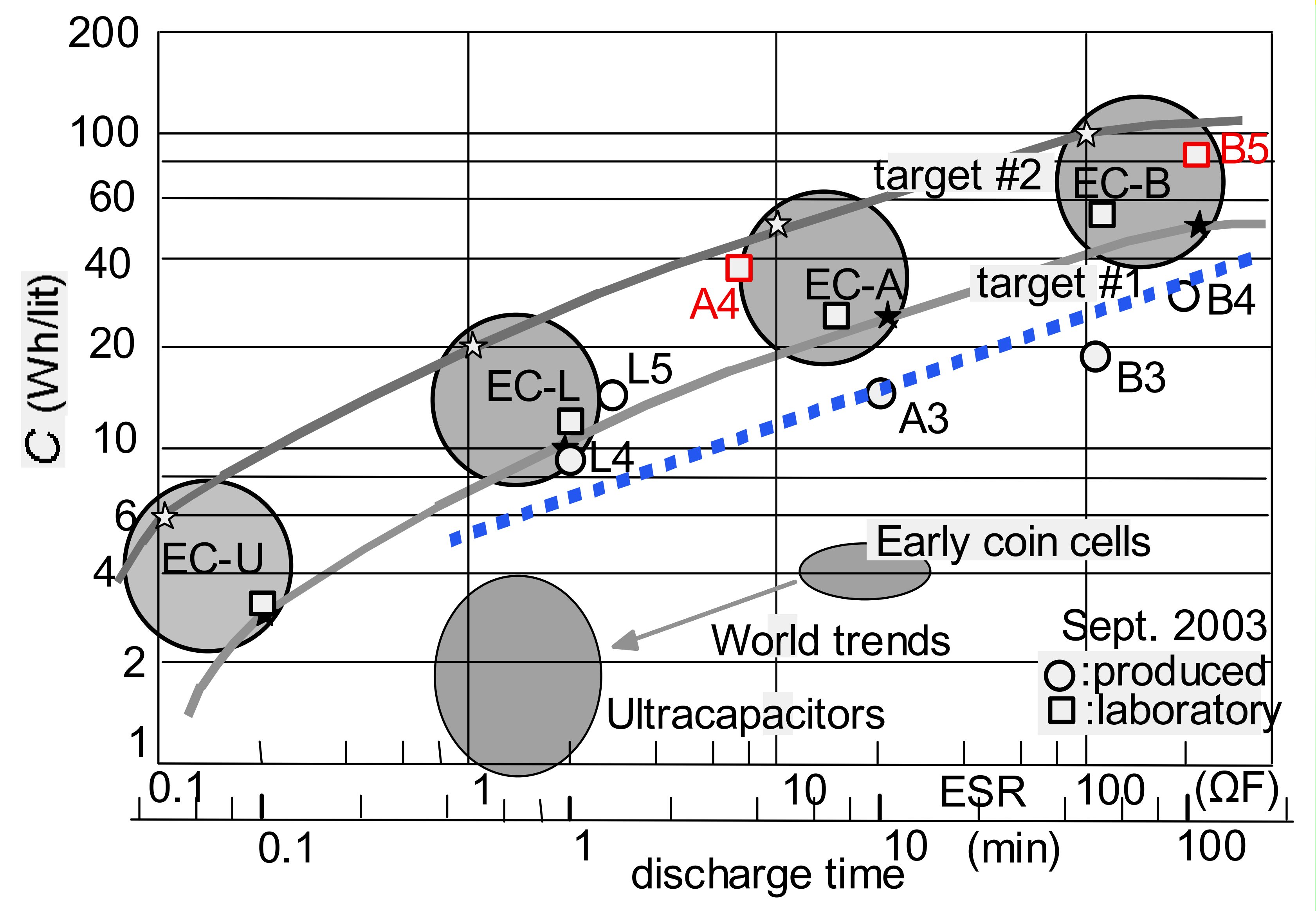
Pd = 1-2**RC/t** .... (3)

Efficiency vs. ESR of Capacitors



"Nanogate Capacitor" from TV

ECaSS Capacitor Map



Ragone Plots of Nanogate Cap.